Studies on S-2 Fiber Glass Insulation for Nb_3Sn Cable

T.T. Arkan, D.R. Chichili and I. Terechkine
Technical Division, Engineering and Fabrication Department
Fermilab, Batavia, IL - 60510

As a part of the structural materials R&D for high field magnet program, S-2 fiber glass sleeve as well as tape were investigated as a possible candidates for Nb_3Sn cable insulation. S-Glass, Owen-Corning Fiberglass name for AF-994 glass, is a high tensile strength glass with superior strength retention properties at elevated temperatures (compared to E-glass). This property is particularly attractive as the reaction temperatures for Nb_3Sn coils run as high as 700 ^oC. The various items investigated in this study are:

(i) Removal of organic binder on the S-2 fiber glass tape / sleeve
(ii) Resizing of S-2 fiber glass with palmitic acid
(iii) Variation of thickness with pressure and percentage overlap
(iv) Variation of thickness with heat treatment (i.e., removal of sizing)

1.0 Removal of Organic Binder

The binder (or sizing - both words are used interchangeably) does two things. It provides protection/lubrication for the glass strand (which is very abrasive) during processing. If it is a direct sizing, it provides compatibility (linkage) between the glass surface and the surrounding matrix (typically epoxies, polyesters, etc.). The other type of sizing is a starch/oil size whose only purpose is to protect the glass during processing (typically weaving, braiding and the like). The S-2 fiber glass we investigated in this study has a starch/oil based binder (Owen-Corning designation: 636). The insulation material as received is quite strong and flexible. Hence it's easy to wrap around the cable if it is a tape or put it onto the cable if it is a sleeve. However the problem arises when we heat treat the coil at around 700 ^oC in argon atmosphere. The organic binder leaves carbon traces (due to lack of oxygen) and this alters both the electrical and mechanical properties of the Nb_3Sn composite. Note that we cannot use oxygen environment because of oxidation of cable surface. Hence the need to remove the binder before putting it on to the cable

Burning or heat cleaning typically removes all traces of the starch oil. Less than 0.1% usually remains. The S-2 fiber glass sleeve was burned at various temperatures and duration's to determine an optimum temperature and duration. Table 1 summarizes these test results. At low temperatures there was no change in color and apparent weight reduction as the temperature was not sufficient to burn the carbon in the binding material. When heat treated at 300 ^oC for 3 hrs in atmosphere, the sleeve tuned into pale brown in color. With the increase in temperature the tape turned into pale white at 400 ^oC and back to pure white at 500 ^oC. However the tape becomes very fragile at high temperatures especially above 400 ^oC. This will not be a concern as we are planning on resizing with palmitic acid. Finally increasing the heat treatment duration from 3 hrs to 16 hrs did not change the color. Hence the effect of temperature is much more dominant than time duration.

#	Material	Curing Conditions	Weight Reduction	Remarks
1	S-2 Sleeve	100 ^oC; 3 Hr	0.00%	White in color
2	S-2 Sleeve	200 ^oC; 3 Hr	0.14%	very light brown in color
3	S-2 Sleeve	300 ^oC; 3 Hr	0.83%	Sleeve turned brown in color
4	S-2 Sleeve	400 ^oC; 3 Hr	0.57%	Sleeve turned pale white
5	S-2 Sleeve	500 ^oC; 3 Hr	0.55%	back to the initial white color
6	S-2 Tape	500 ^oC; 3 Hr	0.63%	White in color
7	S-2 Sleeve	Repeat of 3 at 500 ^oC; 3 Hr	0.09%	turned white in color
8	S-2 Sleeve	Repeat of 5 at 500 ^oC ; 3Hr	0.02%	no change in color
9	S-2 Sleeve	Closed; 300 ^oC; 3Hr	0.58%	Dark brown in color

Table 1: *Insulation burning test results on S-2 glass insulation.*

The change in color with temperature was quantified with a densitometer (as suggested by M. Wake). This densitometer is typically used to quantify the Fuji film. The following figure (Fig. 1) shows the data. Even though the absolute value makes no-sense for us, the relative value is of importance. Note that above 400 ^oC the change in reading in quite minimal. Hence we decided to burn the insulation at 450 ^oC.

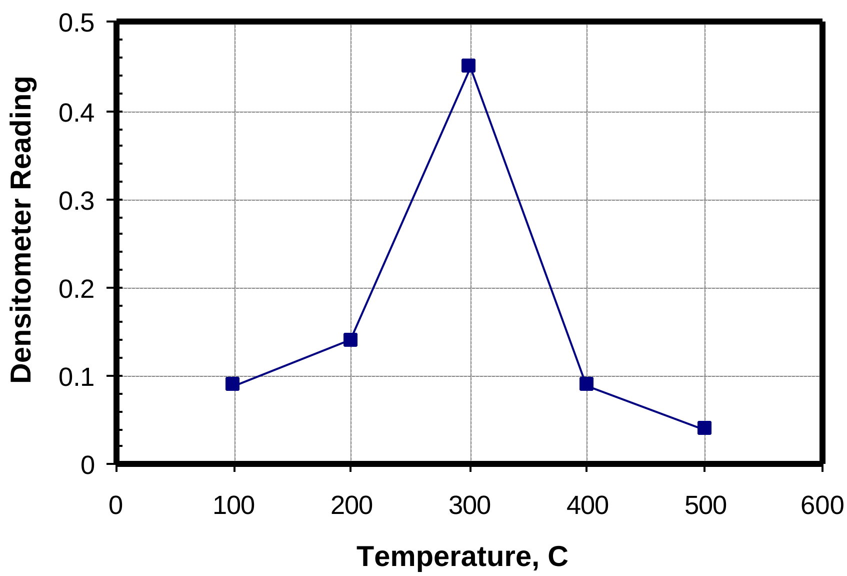

Fig. 1: *Densitometer readings on burned S-2 fiber glass in insulation. Note that the as-received material showed a densitometer reading of 0.06.*

2.0 Resizing of S-2 Fiber Glass

The procedure for resizing the S-2 fiber glass with palmitic acid after initial heat treatment was followed after D20 (LBNL). 24 grams of palmitic acid was added to 300 grams of ethyl alcohol in a 500 ml beaker which resulted in a 8% concentration of palmitic acid in ethyl alcohol. The mixture was then placed on a hot plate and heated up to 38 ^{o}C with continuous stirring using a magnetic stirring unit until the palmitic acid was completely dissolved in ethyl alcohol. According to LBNL this concentration should produce 3-5% coating on the insulation and 5% increase in weight. We tested the solution by dipping a heat treated insulation and then drying it vertically in air. There was about 4.5% gain in the weight of the insulation. The wet insulation can be dried at elevated temperatures (less than 60 ^{o}C) to speed up the process. We are now in a process of designing a system (which consists of spools, a bath and a blower) for resizing the insulation for the first mechanical model.

3.0 Variation of Thickness with Pressure and Percent Overlap

3.1 For S-2 Fiber Glass Sleeve:

The manufacturer (Atkins and Pierce Inc.) quoted a thickness of 7 mils for the sleeve. This value was measured according to the ASTM standards which specifies that the wall thickness of a textile is to be measured by a dial-type micrometer capable of exerting a dead-weight of 3 oz. between the presser foot and the anvil. However we found that the thickness of the sleeve is dependent on pressure and width of the cable.

The sleeve was put on to four NbTi cables which are 0.606 inches wide and onto four Nb_3Sn cables which are 0.48 inches wide. These four stack samples were tested under pressure for determining the variation of sleeve thickness with pressure and width. Four stack samples of bare NbTi and Nb_3Sn cables were also tested so as to subtract the variation of thickness of the cables under pressure. Fig. 2 shows the test results. It is clear from the graph that the thickness of the sleeve decreases with pressure. On NbTi cables, the thickness of the sleeve is only 4.0 mils at about 1000 Psi instead of 7.0 mils at free state. However, the thickness when measured on Nb_3Sn cables is about 4.7 mils at 1500 Psi. This can be explained by the fact that if you take a constant width of the sleeve and stretch it on to a wider cable, the fibers spread and effective thickness decreases. Another important observation was that repeated loading and unloading above pressures of 3500 Psi damaged the S-2 fiber glass. Hence the preform pressure prior to epoxy impregnation should not exceed 3500 Psi.

Finally variation of sleeve thickness along the length (of 15 inches) was measured to check the uniformity of the thickness. There was a maximum of about 0.1 mil (2.5 μm) variation in thickness, which is negligible.

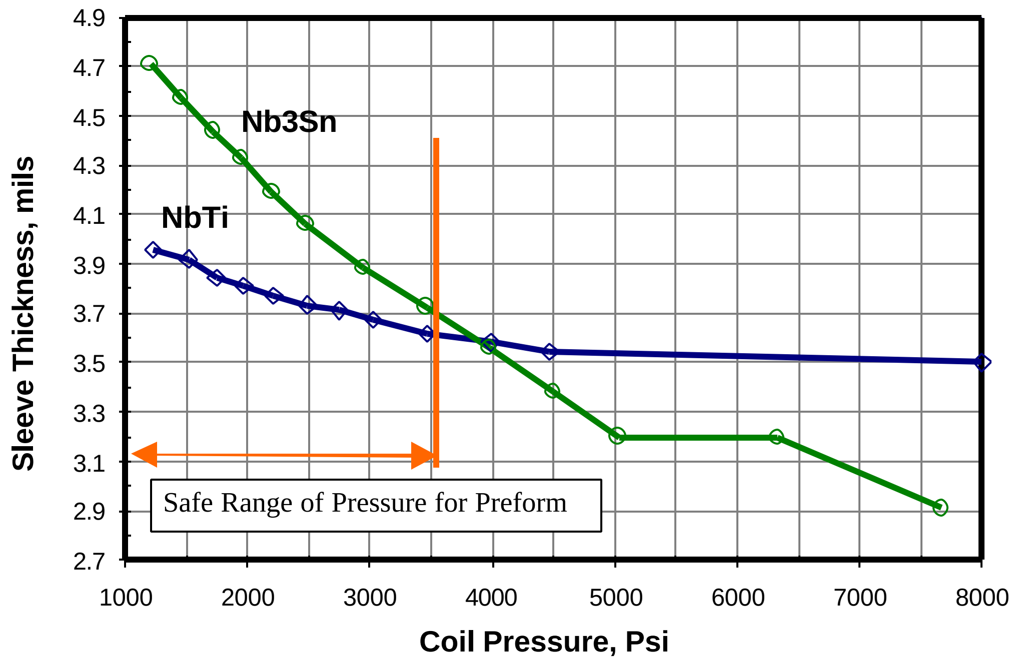

Fig. 2: *Variation of sleeve thickness with pressure and width of the cable.*

3.2 <u>For S-2 Fiber Glass Tape:</u>

As with the sleeve, the tape thickness depends on pressure; however the effective thickness also varies with the percentage overlap. Ten-stack samples with different percentage overlaps (butt lap, 10% overlap, 25% overlap and 50% overlap) were tested at different pressures. Ten stack sample with bare cable was also tested to get the variation of thickness of the cable itself with pressure. The loading history is shown in Fig. 3 and Fig. 4 shows the variation of cable midthickness with percentage overlap and pressure. The initial drop in the thickness is due to the densification of the cables; above 2000 Psi, the variation in thickness is quite minimal.

There is almost a linear increase in effective thickness of tape with percentage overlap (see Fig. 5). The thickness of the tape itself is about 7.5 mils which is the same as that quoted by the manufacturer. Since the tape was wrapped around the cable, the thickness was not effected; infact it might have increased slightly with tension due to wrapping.

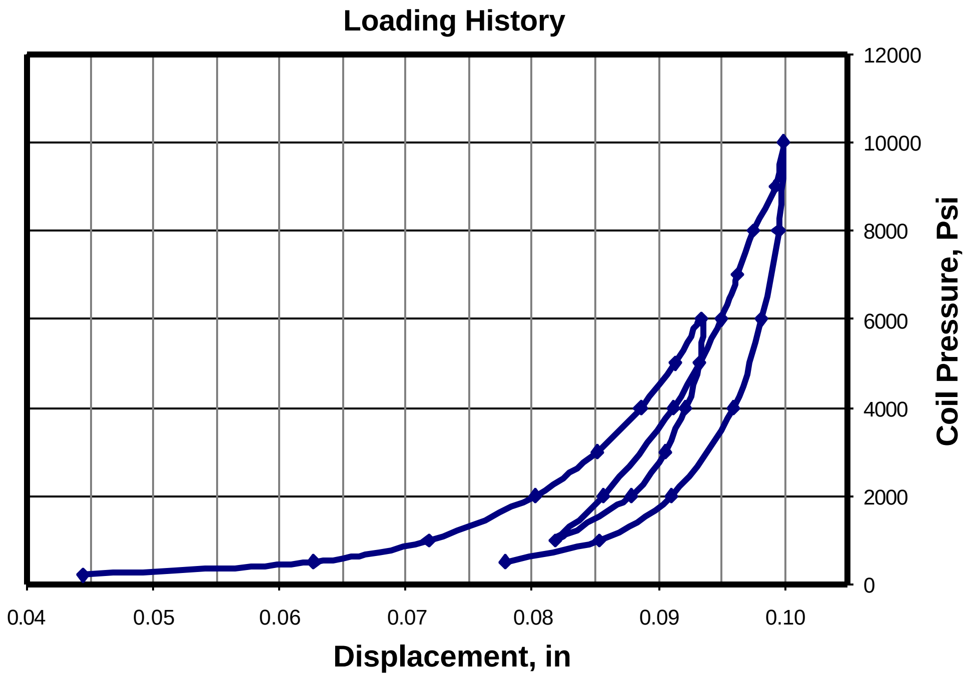

Fig. 3: *Loading history on the ten-stack samples. In the first cycle, the sample is loaded upto 6000 Psi and then unloaded and reloaded upto 10000 Psi and finally unloaded.*

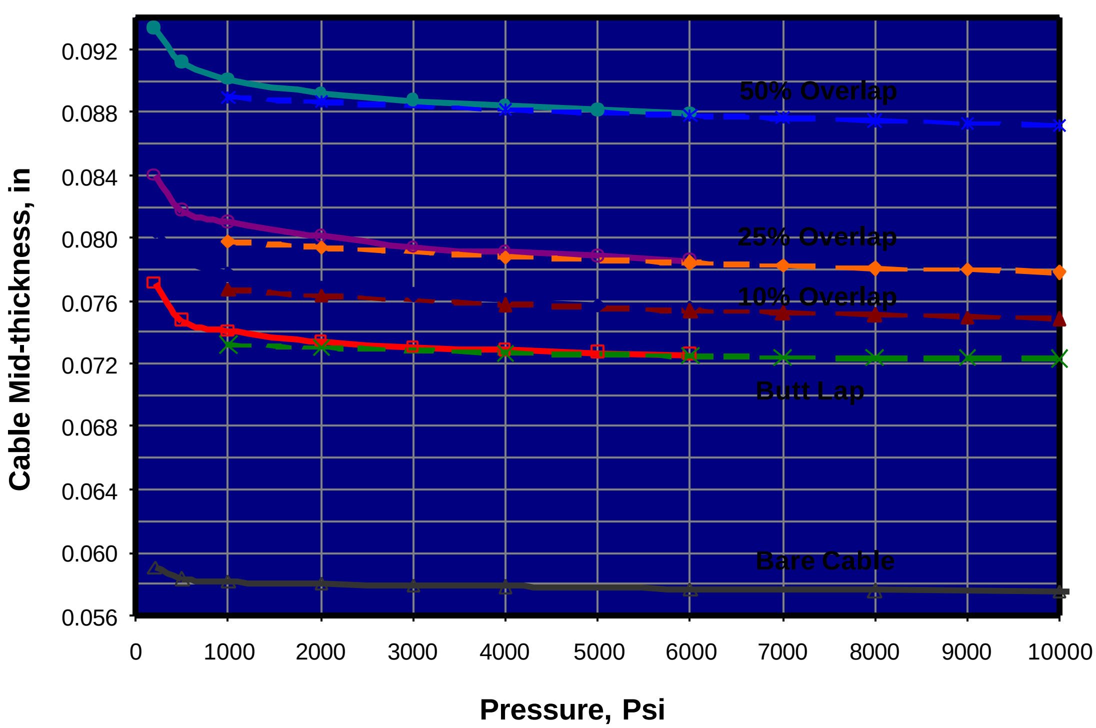

Fig. 4: *Variation of S-2 tape thickness with pressure. The dashed lines are for the second loading step.*

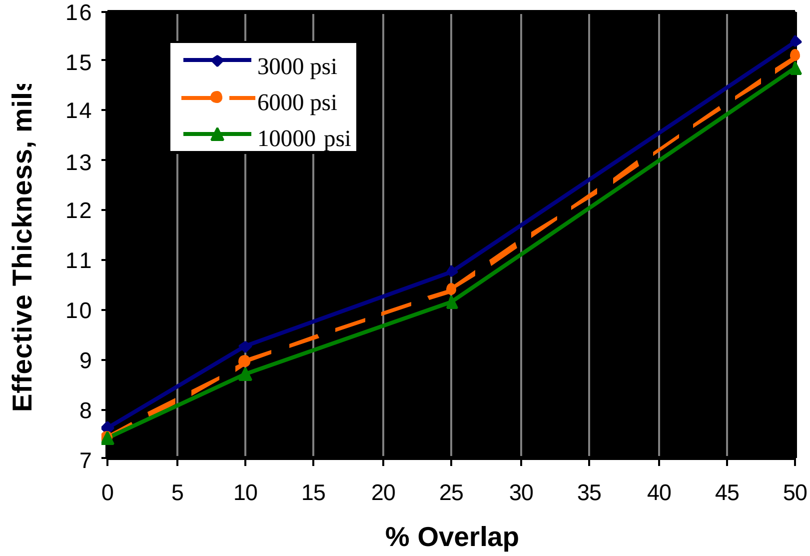

Fig. 5: *Effect of percentage overlap on the effective thickness of the tape.*

4.0 Variation of thickness with Heat Treatment

All the tests shown before were done with as received S-2 fiber glass tape (i.e., with the binder). To study the effect of heat treatment (removal of binder) on thickness of the S-2 glass tape, ten-stack samples were made with S-2 fiber glass tapes that are heat treated in air at 300 ^{o}C and 400 ^{o}C for 3 hrs. Fig. 6 shows the test results for these samples. The thickness of the tape decreases by about 0.5 to 1.0 mil with the removal of sizing.

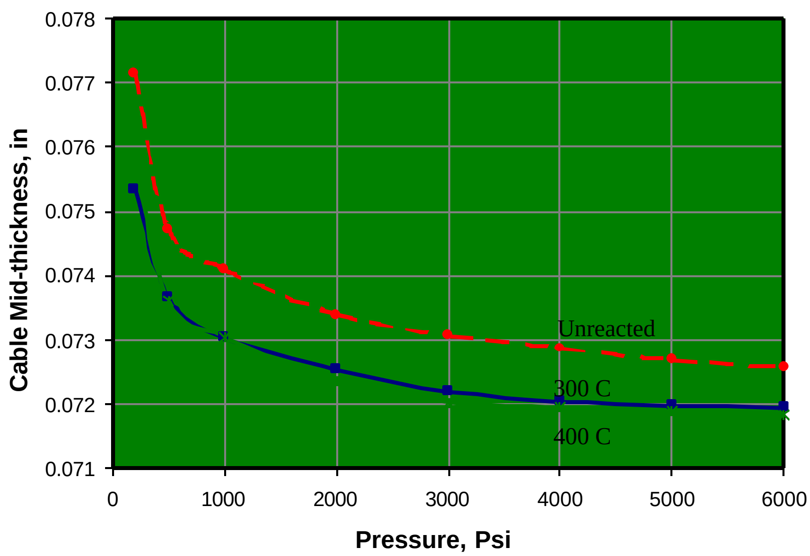

Fig. 6: *Effect of heat treatment on the tape thickness*